ANNUAL REPORT ON GEOTRACES ACTIVITIES IN UNITED STATES

April 1st, 2018 to March 31th, 2019

U.S. GEOTRACES Meetings

The U.S. GEOTRACES Scientific Steering Committee (SSC) met on 20-21 June 2018 at the US National Science Foundation (NSF), thereby facilitating interaction with NSF program officers who oversee support of U.S. GEOTRACES activities. Cruise leaders from GA03, GP16, GN01 as well as GP15 attended the SSC meeting. The SSC reviewed the publication of results from completed cruises and discussed the preparations for GP15. Bob Anderson gave a presentation outlining the principal research objectives of GP17. Bill Landing, co-chair of the GEOTRACES Data Management Committee, led a discussion of GEOTRACES data management activities, and presented preliminary plans for a new GEOTRACES data portal to facilitate all aspects of submitting, compiling and distributing GEOTRACES data.

Cruise-related Activities

North Pacific Meridional Section: Under the leadership of Greg Cutter (Chief Scientist, Old Dominion University) as well as co-Chief Scientists Phoebe Lam (University of California Santa Cruz) and Karen Casciotti (Stanford University), U.S. GEOTRACES completed the Pacific Meridional Section GP15 (Figure 1). Sailing aboard the R/V Roger Revelle, the expedition departed Seattle Washington on 18 September 2018 and arrived in Papeete Tahiti (with a port stop in Hilo, Hawaii) on 24 November 2018.

Principal research targets on the GP15 Section include:

1) Sources of trace elements and isotopes (TEIS) at an active volcanic arc margin (boundary exchange);
2) Boundary scavenging (TEI removal) in productive subarctic waters;
3) Far-field impact on TEI distributions of hydrothermal plumes emanating from the Juan de Fuca Ridge and from the East Pacific Rise;
4) Micronutrient distributions within subarctic HNLC waters where the efficiency of the biological pump is thought to be limited by Fe;
5) Nutrient – biota (biomass, particles, cell quotas) relationships within and between productive regions (coastal and equatorial), HNLC subarctic waters, and ultraoligotrophic waters of the North and South Pacific Subtropical Gyres;
6) Micronutrient supply to the equatorial upwelling regimes via the Equatorial Undercurrent, and TEI transport by other subsurface counter- and under-currents;
7) TEI scavenging and removal under regions of high productivity and particle flux at the equator and at the boundary between the subarctic and subtropical gyres;
8) Differences in regeneration patterns (depths) of exported TEIs between productive vs. oligotrophic waters, including micronutrient/macronutrient ratios;
9) TEI distributions within source regions of intermediate waters;
10) TEI distributions in far-field regions of eastern Pacific Oxygen Minimum Zone waters; and
11) TEI distributions, and their ratios to macronutrients, within the oldest deep Pacific waters.

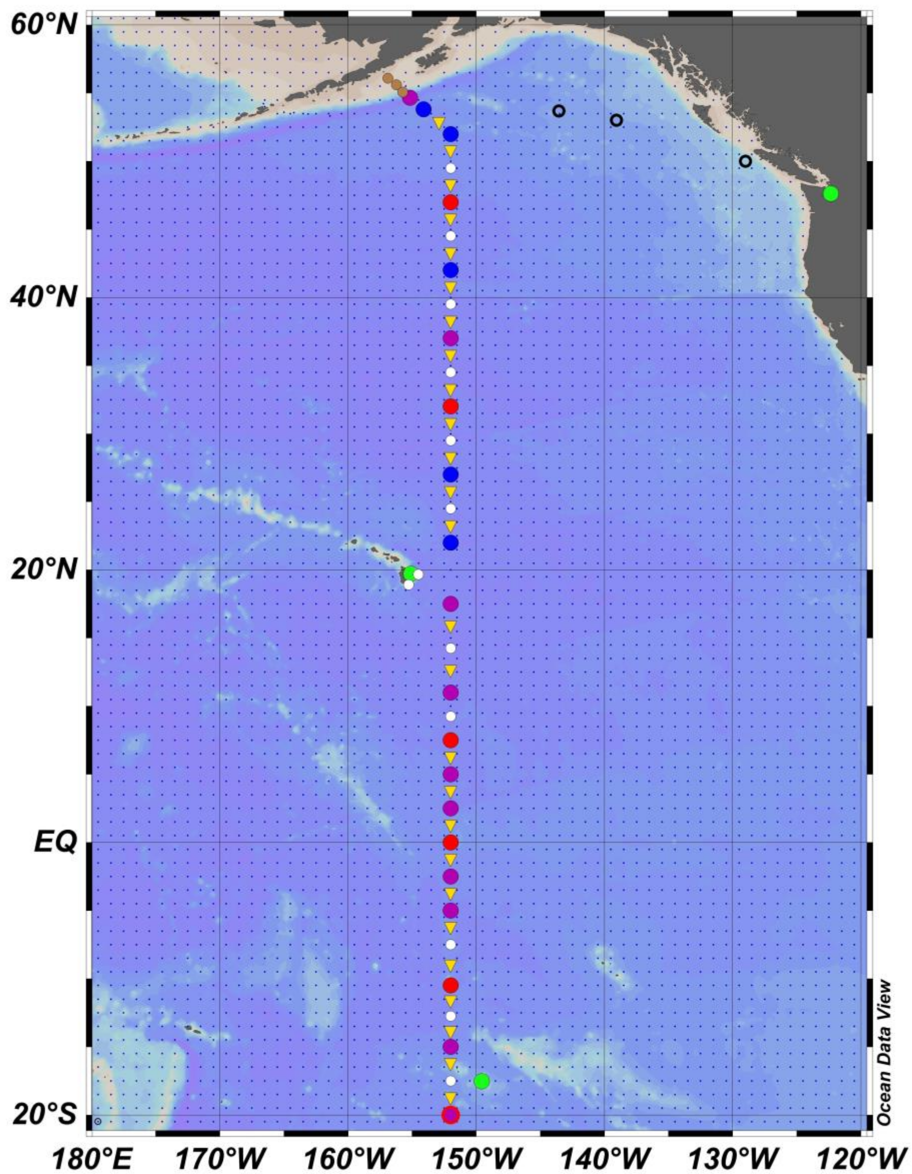

Figure 1. *GP15 Cruise Track: Green circles: ports; open Black circles: rinse stations; brown circles: shelf and slope stations; Purple circles: Full-36-depth stations; Blue circles: Full-24-depth stations; White circles: demi stations; Yellow triangles: intermediate fish samples.*

Although the cruise was only recently completed, already some preliminary results are available to share.

Bill Jenkins (WHOI) and colleagues discovered large helium isotope and trace metal anomalies in the water column above Loihi Seamount, located just to the east of Hawaii.

Figure 2 shows the measured profiles for helium and three trace metals. Helium isotope ratio anomalies (shown in panel a) approaching 400% were observed in the core of a ~300 m wide plume, which appeared approximately 100 m above the seafloor. The size of this anomaly is striking, considering that the open-ocean deep Pacific mid-water plume anomalies are typically of order 20-50%. Corresponding to this maximum was a nearly 22% peak in helium saturation anomalies (panel b). In contrast, over the depth range of the plume, the neon saturation anomaly (shown in panel c, where measurement uncertainties were the size of the dots) was 1.3 ± 0.2%, indistinguishable from intermediate depth measurements made in more distant profiles. This proves that the anomalous helium supersaturation does not come from atmospheric sources.

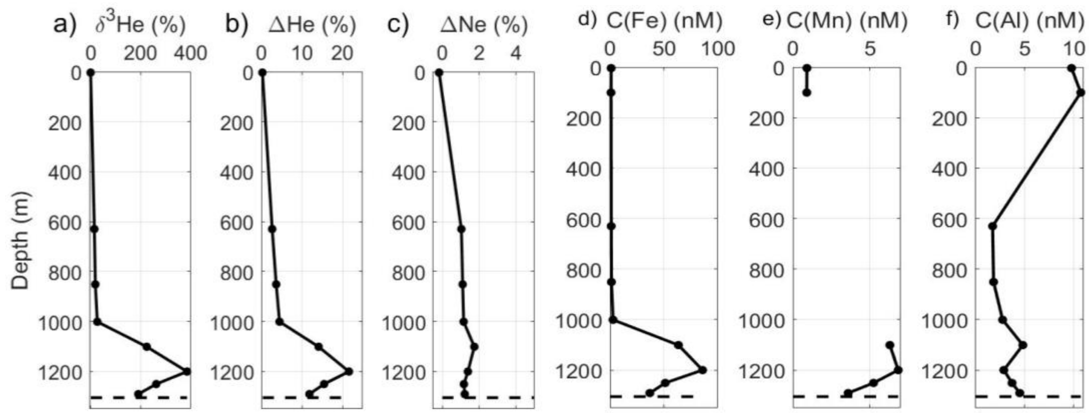

***Figure 2**: Profiles of (a) helium isotope ratio anomaly δ^3He in %, (b) dissolved helium saturation anomaly in %, (c) dissolved neon saturation anomaly in %, (d) dissolved Fe in nM, (e) dissolved Mn in nM, and (f) dissolved Al in nM.*

The relationship between dissolved Fe and excess ^{3}He and between dissolved Mn and excess ^{3}He are represented in Figure 3. The slope of the Fe vs ^{3}He relationship, determined by type II linear correlation as shown by the line in Figure 3a, is 7.7 ± 0.7 x 10^6. This value that is similar to that obtained in the South Pacific (GP16), depending on whether estimated from the downstream decrease in these properties along the core of the transpacific horizontal plume (6.4 x 10^6) or the evolution of water column inventories (7.5 x 10^6). In contrast, observations in the North Atlantic TAG hydrothermal plume (GA03) show dFe concentrations of approximately 60 nmol/kg with a corresponding ^{3}He excess of approximately 0.6 fmol/kg, leading to an Fe:^{3}He ratio close to 1 x 10^8, which is about fifteen times higher than in the Pacific. Observations over the Mid-Atlantic Ridge at around 13°S (GEOTRACES, CoFeMUG, compliant data) yield a similarly high value of ~0.7 ± 0.3 x 10^8.

The Mn:^{3}He relationship (Figure 3b) appears somewhat less precisely constrained at 0.5 ± 0.1 x 10^6 when determined by type II linear regression. Moreover, the "scatter" of points for both Fe:^{3}H and Mn:^{3}He appear structurally similar, with the third highest ^{3}He anomaly falling above the trend line. This points to an interesting feature of both elemental distributions, as seen in the depth profiles of the Fe:^{3}He and Mn:^{3}He ratios in Figure 4. That is, the metal:^{3}He ratio is highest above the core of the plume, and systematically lower in and below the ^{3}He maximum. This observation points to the likelihood that dissolved metal concentrations within the plume are depressed by particulate scavenging.

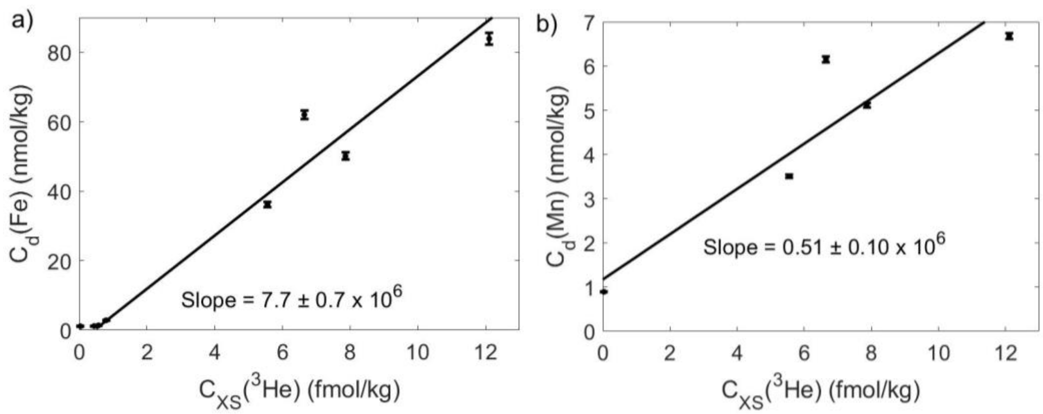

***Figure 3**: The observed correlation between excess ^3He in fmol/kg and a) dissolved Fe and b) Mn, both in nmol/kg.*

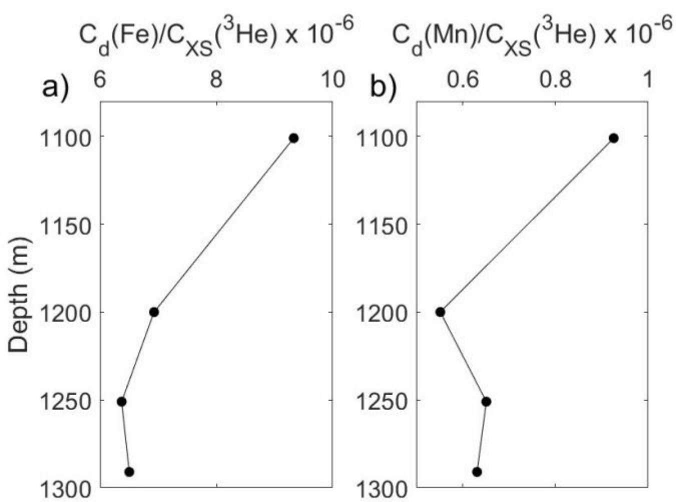

***Figure 4**: The variation vs. depth of a) Fe:^3He and b) Mn:^3He both in units of 10^6.*

Dave Kadko (Florida International University) and coworkers found that the isotope ^7Be can be used to estimate the Bulk (wet+dry) deposition velocity (Vb) for trace elements (TEs) delivered by aerosols, where:

Vb = (Flux ^7Be)/(aerosol ^7Be concentration) = (Ocean inventory ^7Be x λ))/(aerosol ^7Be concentration)

and where λ =^7Be decay constant. The flux of TEs into the ocean = [aerosol TE] x Vb.

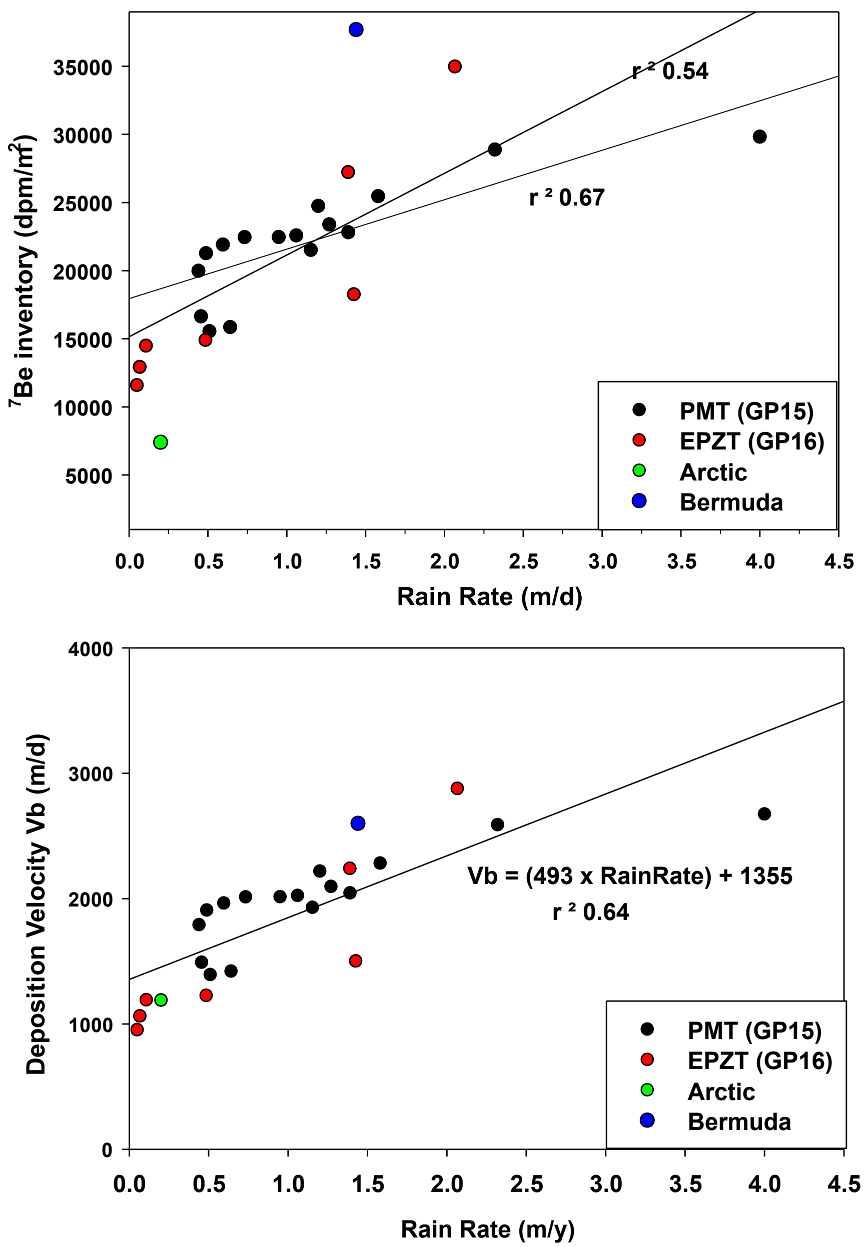

Figure 5. *Top: Globally, the ^{7}Be ocean inventory is to first order dictated by precipitation (R^2=.54). Data from the recent US Alaska - Tahiti cruise (GP15), transecting large gradients in rainfall are included (R^2=.67).*
Bottom: Using the average aerosol ^{7}Be concentration for each region, the Vb is calculated and plotted against rain rate. The y intercept (zero rain) corresponds to a dry deposition velocity of 1355m/d, which is close to the value of 1000m/d often accepted for that parameter. The bulk deposition velocity for TEs can be predicted by the precipitation rate. Aerosol fluxes of TEIs will be compiled once the analysis of GP15 aerosol samples has been completed.

Alan Shiller (University of Southern Mississippi) shared results for barium and for methane measured along the GP15 line (Figures 6 and 7).

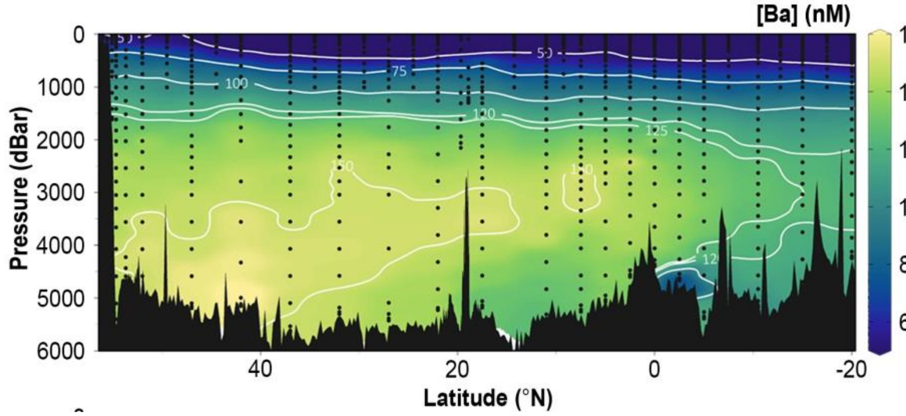

Figure 6. *Dissolved Ba along GP15 produced by Peng Ho, Melissa Gilbert, and Laura Whitmore. The dissolved Ba section is in general agreement with previous Pacific data and the southern end of the section matches well with earlier GP16 Ba data at that location. Comparing the Ba with previous dissolved Si data, the distributions are similar, though the mid-water increase in Ba is a little more gradual than Si and the deep water maximum is lower in the water column for Ba than Si.*

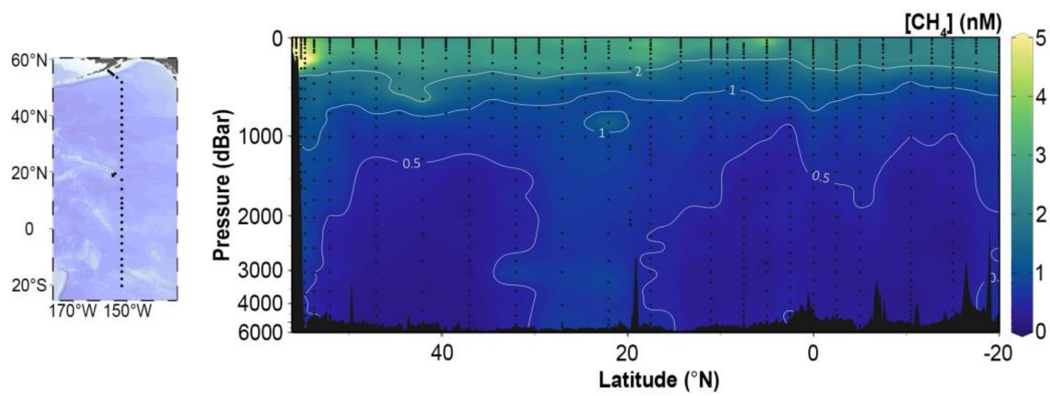

Figure 7*. Methane along the GP15 section. The CH_4 data, produced by Laura Whitmore and Virginie Sanial, show the expected distribution with highest concentrations in shallow waters, tapering off rapidly with depth. The highest concentrations were observed near the Aleutian margin. There was also a slight increase in the Loihi plume near Hawaii.*

New Funding

The U.S. GEOTRACES project office received a 3-year renewal of its funding from the US National Science Foundation, beginning 1 October 2018.

Planning for future expeditions

South Pacific Meridional Section The management team for GP17 (Tahiti to Antarctica) is still being constituted. It is anticipated that the cruise leaders will be finalized by the next meeting of the U.S. GEOTRACES SSC (20-21 June 2019 at the U.S. NSF). The anticipated timeline for GP17 is that the cruise leaders will submit a proposal to the U.S. NSF in February 2020 to request support for management of the section, including ship time and shared sampling needs (e.g., trace metal clean sampling system, nutrients, hydrography, *in situ* pumps). Individual PIs will submit their proposals to NSF in August 2020. The target window for GP17 is December 2021 – February 2022.

Gulf of Mexico Alan Shiller continues to hold individual meetings with scientists from other programs to explore options for partnering in studies of the Gulf of Mexico within the 2025 – 2026 time frame. It was decided at the 2018 meeting of the US GEOTRACES SSC that this will likely be the last U.S. GEOTRACES cruise, unless something happens to prolong the program. The Gulf of Mexico expedition may be operated more like a process study, serving as a transition into a new US program that emphasizes process studies to investigate TEI biogeochemistry.

Synthesis

Investigators from the US are contributing to the growing effort to synthesize GEOTRACES data. Four synthesis publications led by US authors appeared during the past year. Full references are given in the publication list that follows.

Hayes et al. (2018a) combined data from thorium isotopes measured along the GA03 section with concentrations of several trace elements measured along the same section to estimate replacement times for those elements. The calculated replacement times are effectively equivalent to the residence time of each element with respect to its supply from dissolution of lithogenic material. These estimates are most useful for elements with very short residence times that are delivered primarily by dust, such as Fe and Mn.

Hayes et al. (2018b) compared four different pairs of naturally occurring radionuclide "rate meters" (^{234}Th-^{238}U, ^{230}Th-^{234}U, ^{228}Th-^{228}Ra and ^{210}Po-^{210}Pb) to estimate fluxes of particulate organic carbon (POC), phosphorus (P) and several trace elements on particles collected by in situ filtration along the GA03 section. Radionuclide-based fluxes were compared against annual average fluxes collected by sediment traps deployed by the Ocean Flux Program near Bermuda. Agreement was good for fluxes of POC and for certain trace elements, but less good for others.

Kadko et al. (2019) used ^{7}Be to estimate fluxes of aerosol-associated trace metals to the central Arctic Ocean (GN01). Residence times of trace metals in the upper water column were calculated using measured water column inventories of the metals and the calculated fluxes from aerosols. The results produced unreasonably large residence times for metals within the Transpolar Drift, indicating that sources other than aerosols are important for these metals in the central Arctic Ocean. Both rivers and the Siberian continental shelf have been proposed as potential sources.

Black et al. (2019) constructed a 2-D mass budget for Co, Mn and Cd along GP16 in the SE Pacific Ocean. Surface fluxes of these elements from the Peru margin into the ocean were calculated using previously published ^{228}Ra data to estimate horizontal mixing rates. Fluxes of each metal exported to depth from surface waters were calculated using ^{234}Th. A major finding of the paper is that the sinking fluxes of exported metals can be accounted for by mobilization from shelf and upper slope sediments and offshore transport by mixing. Dust is not a significant source for these metals along GP16.

GEOTRACES supports synthesis of findings along three themes: 1) Supply and removal of TEIs at ocean interfaces, 2) Internal cycling of TEIs within the ocean, and 3) geochemical proxies for past changes in ocean conditions. In support of the 3rd theme, Bob Anderson chaired the planning committee for a synthesis workshop co-sponsored by GEOTRACES and by PAGES (Past Global Changes program) held in Aix-Marseille France (3-5 December 2018) https://geotracespages.sciencesconf.org. Anderson also served as co-chair of the workshop.

Outreach and Capacity Building Activities

Greg Cutter (Old Dominion University), Ken Buesseler (WHOI) and Bob Anderson (Lamont-Doherty Earth Observatory) participated in the GEOTRACES-China cruise-planning workshop (5-6 May 2018, Xiamen University) to assist Chinese colleagues in planning for the first open-ocean GEOTRACES-China expedition in the western Pacific Ocean. Cutter had previously spent two weeks with the Chinese investigators training them at sea in the use of a trace metal clean rosette sampling system.

Publications (GEOTRACES, GEOTRACES Compliant and GEOTRACES-related)

During the past year US GEOTRACES investigators published a total of 52 peer-reviewed journal articles, including papers published by lead authors in other nations for which U.S. GEOTRACES investigators serve as co-authors.

In addition, 10 PhD dissertations and 1 masters thesis were completed, and one data product was released.

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